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Assessment of solar-wind power plants in Afghanistan: A review

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ABSTRACT

The integration of renewable energy sources like wind and solar is very important to combat climate change, also to reduce carbon dioxide in many countries. Afghanistan with low energy consumption has a great potential for using renewable energies., also therefore, this study attempts to find suitable locations for constructing solar-wind power-plants using solar and wind data from 46 stations by HOMER and GIS softwares. Based on the available data, results indicate that Uruzgan and Balk stations, each with $12006 and $13941 respectively, have the lowest and highest net present cost. Also, in terms of using renewable energies (%) and producing CO_2 emissions, Qandahar with 99% and 7 kg/yr and Balkh with 87% and 235 kg/yr are respectively the best and the worst stations from an environmental perspective. According to the results, average price per kWh of energy generated in Afghanistan is $0.638, average percentage of using renewables is about 96.46%, and the average rate of producing CO_2 emissions is 70.39 kg/yr. The analysis results of turbulence intensity parameter shows that 23 stations in Afghanistan have a low turbulence intensity which means the mechanical components of wind turbines are under low fatigue loads and the rest of stations have a medium turbulence intensity which means the mechanical components of wind turbines are under medium fatigue loads. The highest and lowest values of turbulence intensity parameter are associated with Sindand and Qunduz stations respectively. Given the apparent and urgent need to develop renewable energy sources in Afghanistan, results of the present study, in addition to improving people's lives, could accompany economic development.

1. Introduction

Afghanistan is located in Asia which occupies an area of about 647,800 km^2. Its population is mostly consisted of young people and children who mainly live in rural areas. Afghanistan is a war-zone country which politically and socially is unstable. Yet, there is a global determination for international cooperation with Afghanistan government to help the country. Javed et al. [1] presented some strategies for deciding about the status of renewable energy infrastructures in Afghanistan. These strategies have been developed by considering the war-torn status of this country and its states. Statistics provided by Afghanistan government shows that permanent access to electricity is only available for 10–15% of people which is one of the lowest access rates among countries worldwide. Also, this percentage of access to electricity is much lower in rural areas. There is a higher access to permanent electricity sources in large cities of Afghanistan like Kabul, Mazar-e Sharif, Herat, Qandahar, and Jalalabad, which are connected to public electricity supplies. Rostami et al. [2] mentioned that from 340,000 households consuming national electricity in Afghanistan, 182,000 of them live in Kabul. However, electricity consumption per capita in this country has been reported to be 140 kWh in 2011 which is much lower compared to the global average of 3060 kWh.

Shoaib et al. [3] showed that in some states like Parwan, more than 90% of people had access to portable waters which could not be seen in other states of Afghanistan. In this area, there are 10 small hydro-electric plants each with a capacity of 5 MW. Moreover, there are 2 wind power-plants with a capacity of 1 MW. Yet, many of the households use solar systems to provide for their energy need.

Since Afghanistan is a mountainous country with snow-covered mountains, in many months of the year, it is not confronted with the problem of runoff water. Also, the country is capable of exploiting solar and wind energies. However, calculating the implementation costs of equipment is very complicated. Sadiqi et al. [4], illustrated two different scenarios in order to determine design and implementation costs of hybrid energy systems. Strategies laid out in this research have the potential of encouraging the use of hybrid energy in some areas of Afghanistan.

Successive years of war in Afghanistan have slowed down the

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growth of energy systems in this country. The use of hydroelectric sources in this country is made precarious by the geographical diversity and climate change, since these areas are susceptible to storm and flood. Despite all these complications, the electric capacity of energy sources has observed a nearly 140% increase in recent years. U.S. Agency for International Development (USAID) investment has provided 200 MW of energy for Afghanistan [5]. Rostami et al. [2] illustrated that the capacity of domestic power generation systems in Afghanistan is 240 MW for hydroelectric power and 220 MW for thermal power plants. Furthermore, extra demand for electricity is mostly supplied by electricity import (about 80% of total energy).

Renne et al. [6] used experimental data from U.S. National Renewable Energy Laboratory (NREL) for Afghanistan and Pakistan and also Geospatial toolkit (GST) and HOMER Software to study the available wind and solar energy sources for these countries.

Given the environmental conditions of Afghanistan and the fact that using small-scale hydroelectric plants, wind turbines, and solar energy are suitable for this country, Sadiqi et al. [4] studied rural electrification using a combination of renewable energies. They utilized HOMER software to determine the most economically optimal combination of renewables and presented two scenarios for power provision: one was a combination of renewables with battery bank and the other was the combination of renewables with diesel generator. Finally, HOMER results in terms of annual electric energy storage suggested that net cost and energy cost per kWh for renewables combination with battery bank and with diesel generator were $512516 and $0.149 for the former and $331928 and $0.105 for the latter, respectively. Thus, due to its lower cost, combination of renewables with diesel generator is a more cost-effective alternative.

Given the fact that, due to high costs of development, it is impossible to electrify all areas of a country using a power grid. Palit [7] studied electrification of rural areas and other areas deprived of power grid in Southern Asia, including Afghanistan, using solar energy. In this study, development of necessary infrastructures and improvement of buildings' technical capacity in those areas were presented as some strategies that make the use of solar renewable energy more economic and feasible.

Bhandari et al. [8] studied the construction conditions of a hydroelectric power-plant for four Northern provinces of Afghanistan including Badakhshan, Baghlan, Balkh, and Takhar. They also investigated the socio-economic effects of this project. The main studied parameters were: distribution of hydroelectric power plants, construction costs, implementation models, power consumption tariffs, and society satisfaction. Finally, it was concluded that decentralization of hydro and solar power plants was essential for electrification of these provinces.

Shoaib et al. [3] examined the socio-economic effects of renewable energy projects for cities and communities of Afghanistan. They suggested that these projects might improve social and economic conditions and also create job opportunities [3].

Ershad et al. [9] studied the potential of grid-connected solar and wind power-plants for two populous cities of Afghanistan, namely Balkh and Herat. Their study revolved around influential factors, power consumption, wind speed, and solar radiation. They concluded that solar and wind power-plants in both provinces acquired penetration levels of 65–70% without curtailment which led to less dependency on neighboring countries for generating required electricity, lower consumption of fossil fuels, lower costs, and also less environmental pollution.

Anwarzai and Nagasaka [10] performed a feasibility study of utilizing wind and solar energies for Afghanistan using Multi-Criteria Decision Analysis (MCDA) and GIS techniques. Using available data and based on topographical, environmental, and also cost-effectiveness considerations, they chose appropriate locations for application of these energies. Finally, it was concluded that the potential of annual electricity generation from wind and solar energies were 342,521 kWh and 140,982 kWh, respectively. Also, another 6000 kWh was obtained from concentrating solar power (CSP) which were totally 160 times the available sources of power generation.

Jahangiri et al. [11] studied the electrification of three villages of Cham-e Zin, Cham-e Ali, and Chelevan in Chaharmahal Va Bakhtiari Province in Iran using renewable energies. Economic optimization was performed by HOMER software and results indicated that solar cells could meet 97%, 57%, and 96% of energy demand for Cham-e Zin, Cham-e Ali, and Chelevan villages, respectively. While the rest were provided by diesel generator.

Shaahid et al. [12] used HOMER for a potentiometric study on the development of wind farms in Turaif, Saudi Arabia. The aim of this study was to reduce the use of fossil fuels. The studied parameters were monthly and annual electricity production by 30 MW wind farm, the price per kWh of electricity generated, and capacity factor. Results suggested that for 50 m altitude of wind turbine installation, 39,752 MWh of power was generated annually and the price of generated power was $0.0579 per kWh. Also, 1598 t of CO_2 emissions could have been saved annually.

Nag and Sarkar [13] conducted a sensitivity analysis and analyzed a hybrid renewable energy system for providing the future energy demands of a rural area in India. Five different scenarios were investigated including solar cells, wind turbine, diesel generator, biomass generator, and hydropower. HOMER software results showed that for the years 2012–2021, 2022–2031, 2032–2041, and the period between 2042 and 2051, the price per kWh of generated power would be $ 0.3653, 0.247, 0.242, and 0.241, respectively. For mentioned time periods, the amount of kWh of electricity produced annually would be 133,045, 170,948, 179,018, and 179,303, respectively.

Mehrpooya et al. [14] conducted a techno-econo-environmental analysis on a hybrid power generation system for a laboratory at Tehran University in Iran. They used HOMER software and studied four different scenarios including diesel generator, solar cell, battery, and hydrogen storage system. Results indicated that substituting batteries for diesel generator led to a remarkable increase in the installed capacity of solar panels. Due to high costs of investing on fuel cell systems and also due to the low price of diesel in Iran, the solar cell-biomass generator-battery-converter system was recommended as a cost-effective system.

Jahangiri et al. [15] used HOMER to evaluate the simultaneous heat and power generation for a residential building at Zarin Shahr, Isfahan. Four various scenarios of wind, sun, and biomass (off-grid and grid-connected with dump load and without dump load systems) were studied. Results indicated that if the studied areas were 2.58 km away from the national grid, using the grid power would be more suitable than using the biomass. Otherwise, according to the economic optimization by HOMER, it was recommended that a combined system of renewable energies comprising solar cells, biomass generator, battery, and converter would be used.

Due to prolonged wars in Afghanistan and infrastructure maintenance gap in energy sector of this country, high cost of kerosene and diesel generator, and also the fact that using renewable energy, besides improving people's lives, will bring economic development, and given the fact that, till now, no comprehensive work has been conducted on using hybrid solar-wind energies in this country, in the present work a GIS Software is used to identify areas prone to using wind-solar energies, and then, applying HOMER Software, utilization of renewable energies is economically and environmentally evaluated in all 46 available stations. Studied parameters are: amount of emissions, cost

per kWh of energy produced, percentage of using renewables, excess electricity production, and monthly shares of wind and solar energies in providing required power.

2. Status of energy consumption and renewable energies in Afghanistan

With 49 kWh of electricity consumption, Afghanistan is one of the countries with the lowest energy consumption [16]. Having a daily average radiation of 4–6.5 kWh/m^2, 300 sunny days [17], hydroelectric dams in mountainous areas [18,19], and a high potential of biogas energy due to habitation of 70% of people in rural areas [20], this country has a high potential for renewable energies. It is noteworthy that due to prolonged wars in Afghanistan and lack of energy infrastructures maintenance, generation capacity is lower than the potential level [18]. Thus, about 73% of required electric energy is bought from neighboring countries [20,21].

There are a few small-scale renewable energy projects for using solar energy for water heating, lighting, and using hydroelectric energy in small scale (5–100 kW) [22], and people mostly use wood and coal for their heating and cooking requirements. There is a 304 MW installed capacity of electricity generation by hydropower, in which 183 MW is in operation [19]. The biggest operational renewable energy system in Afghanistan is a 1 MW solar-battery installation in Bamyan Province [23]. Also, despite Afghanistan having some areas suitable for using wind energy, no attention has been given to this energy source [24].

According to aforementioned considerations and given the fact that about 75% of households suffer from respiratory diseases caused by smoke produced from consumed fossil fuels and also considering that about 20% of rural population in Afghanistan have access to electricity [25], with 70–80% of total population deprived from electricity [20,21], there is an evident and urgent need for development of alternative energy sources. However, long-term development plans, by considering annual growth of 8.7% in power consumption [16], call for an increase in the number of people connected to grid to 83% by the year 2032 [21].

The shares of electric energy produced in Afghanistan by source types in 2010–2011 are presented in Table 1 [26,27]. Table 1 illustrates that electricity generation from hydropower has been 20 times more than diesel and about one-third of imported electricity in 2011. Another important point observable in Table 1 is a 9.2% decrease in hydropower generation directly imposed on import sector.

Due to such reasons such as low operational costs, technical simplicity, and short installation and commissioning time, it seems that using hybrid solar-wind energies will be a desirable solution. Accordingly, maps of annual average solar radiation and wind speed are given in Figs. 1 and 2. As shown in Fig. 1, southern half of Afghanistan has more potential for using solar energy. The highest radiation, with a radiation intensity of 5.63 kWh/m^2-day, is recorded for LaskarGah station located in between 64 and 66 East longitude and 30–32° North latitude. Furthermore, Fig. 2 shows that western and east-northern parts of Afghanistan are in a more suitable position for using wind energy; a fact also reported in previous works [24]. The highest wind speed with a value of 5.9 m/s is reported for Fayazabad station located in between 70 and 72° east longitude and 36–38° north latitude.

The most commonly used approach for illustrating frequency distribution of wind speed is Weibull distribution method which is more flexible than other methods as following [28–30]:

Table 1
Electricity generation in Afghanistan by source types in 2010–11 [26,27].

Source types	2010 [GWh]	2010 share [%]	2011 [GWh]	2011 share [%]
Hydro	909	35.2	802	26
Thermal (diesel)	101	3.9	40	1.3
Import	1574	60.9	2244	72.7
Total	2586	100	3086	100

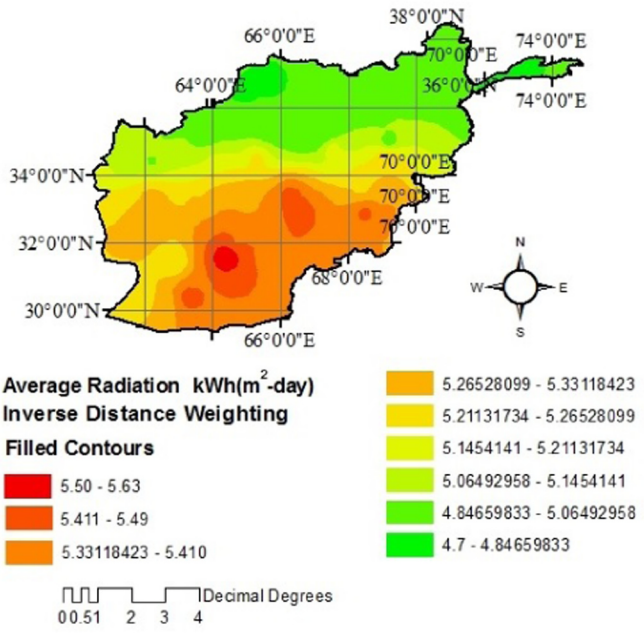


Fig. 1. Annual average solar radiation map.

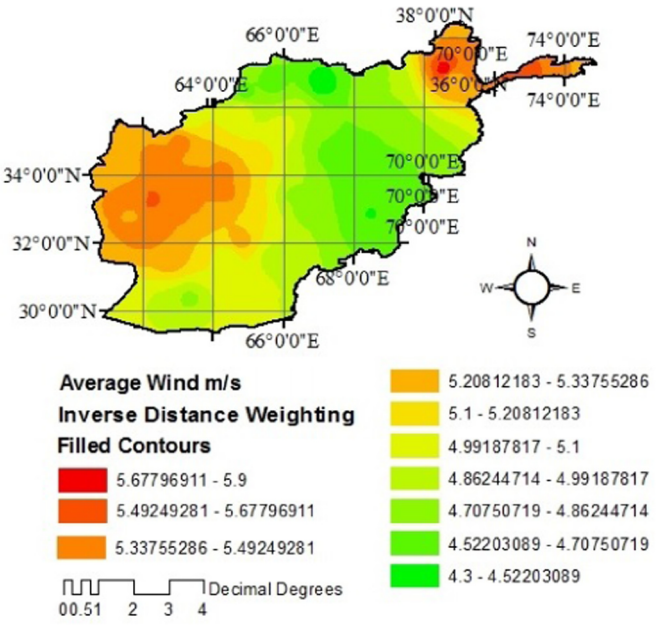


Fig. 2. Annual average wind speed map.

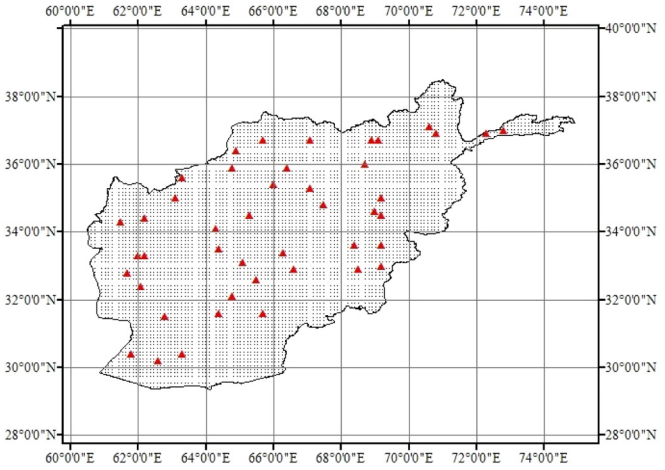


Fig. 3. Location of studied areas.

$$F(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

where v is wind speed (m/s), k is a dimensionless parameter called shape factor, and c is parameter named scale factor (m/s). There are various ways to calculate c and k parameters, one of which is curve fitting conducted by Homer Software. The shape parameter, k, shows how the wind speed is distributed and the scale parameter, c, indicates how windy the region is [28–30].

It is noteworthy that since, in addition to solar radiation intensity and wind speed, other parameters such as cloudiness index, sunny hours, relative humidity, air temperature, annual peak load should also be considered. Therefore all 64 station must be evaluated by HOMER to determine their economic and environmental situations.

3. Data required for simulation

Data on solar radiation, wind speed, and clearness index for 46 studied stations were extracted from NASA Website (RETScreen 4 Software Package) and presented in Appendix Table 1. Location of

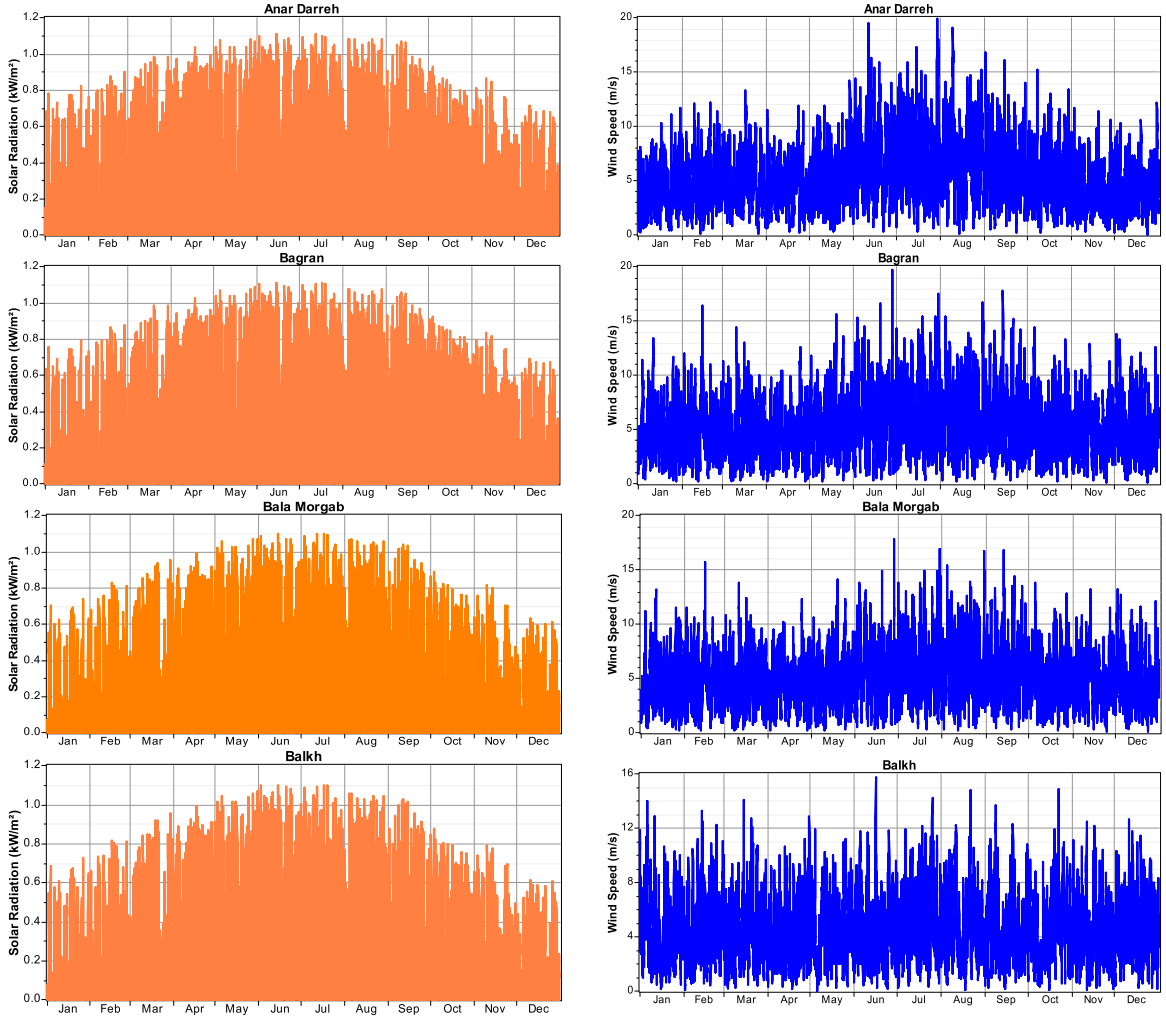


Fig. 4. One-year histograms of wind speed and sun radiation of stations.

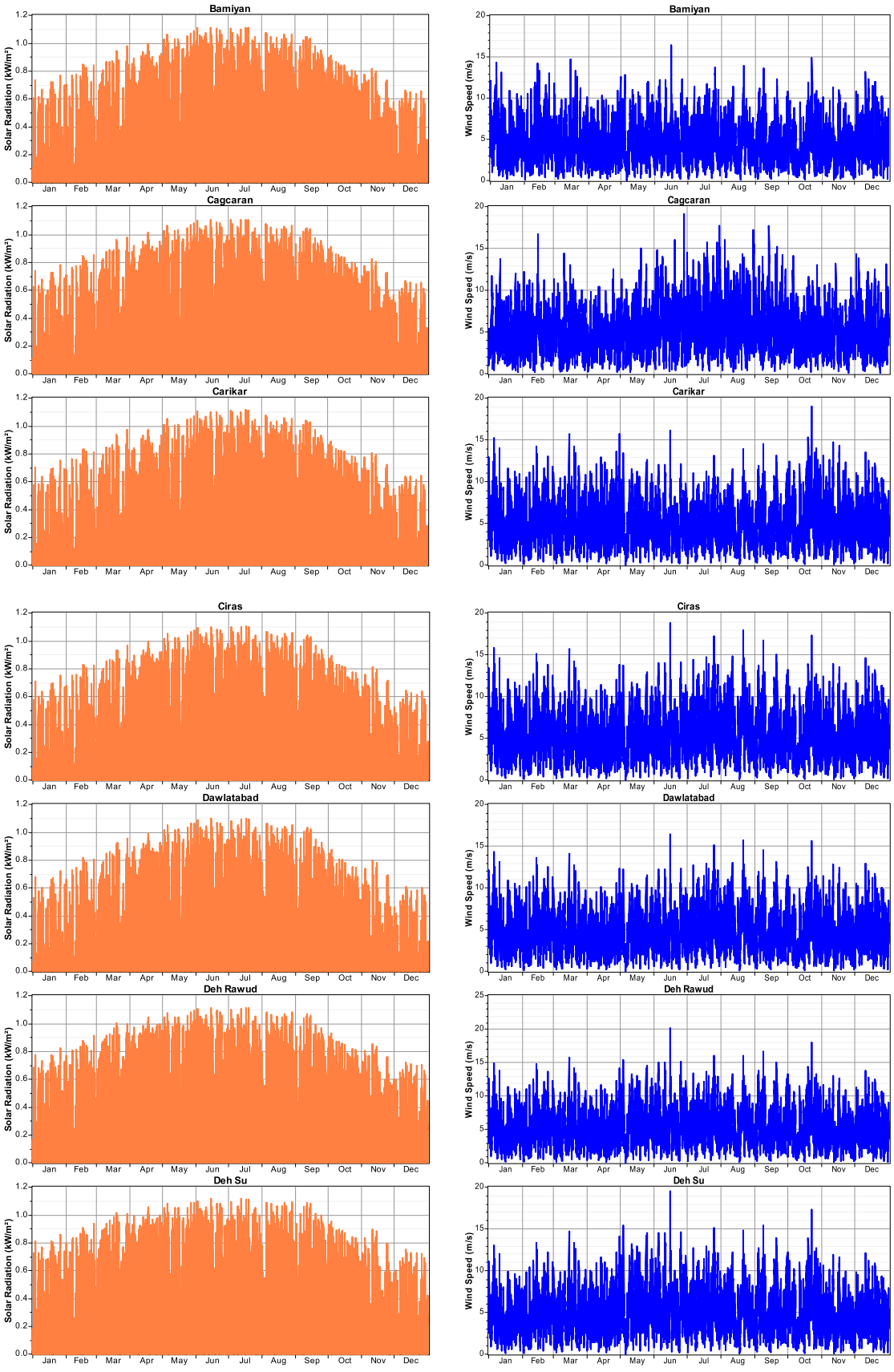
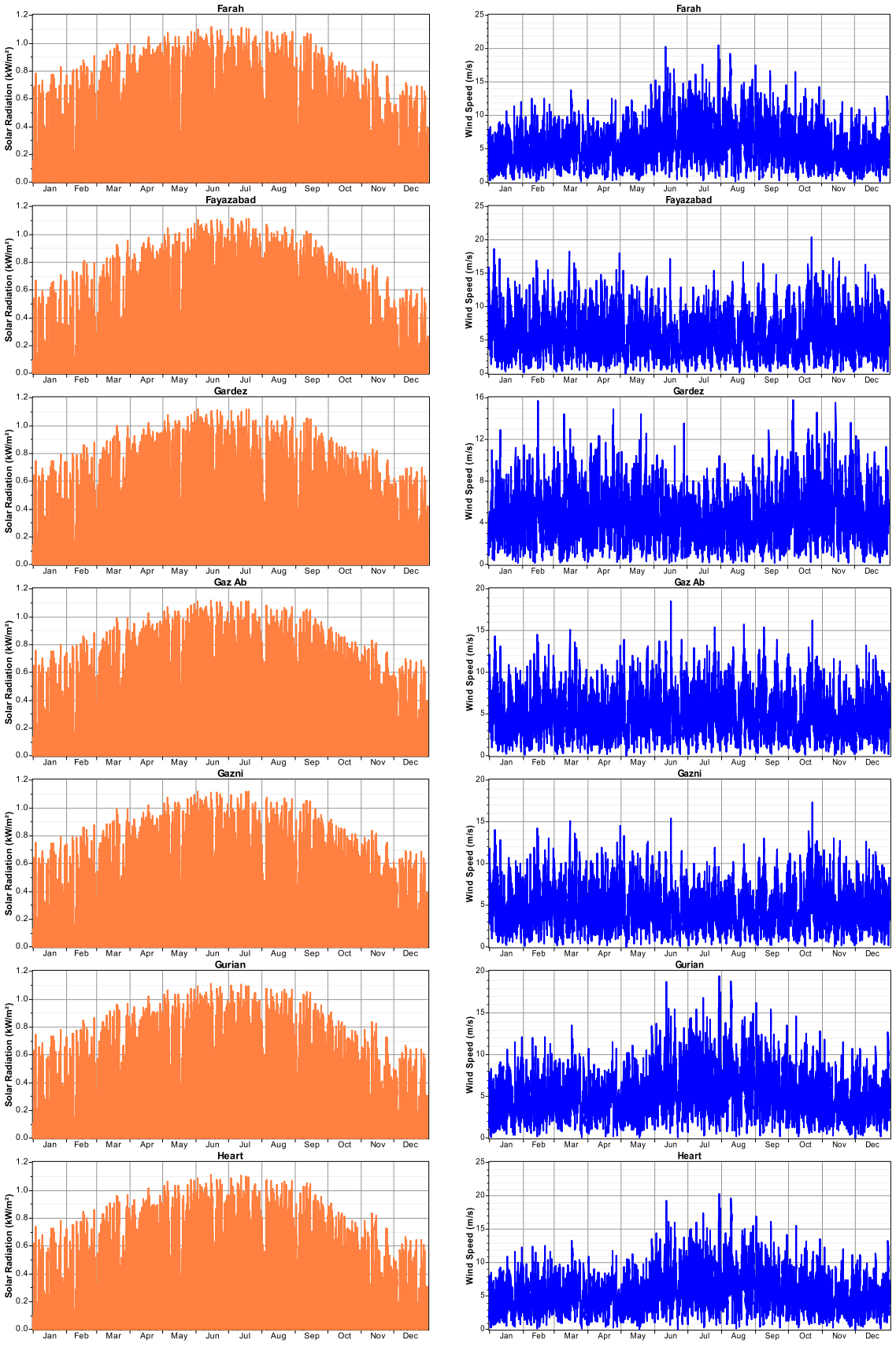


Fig. 4. (*continued*)



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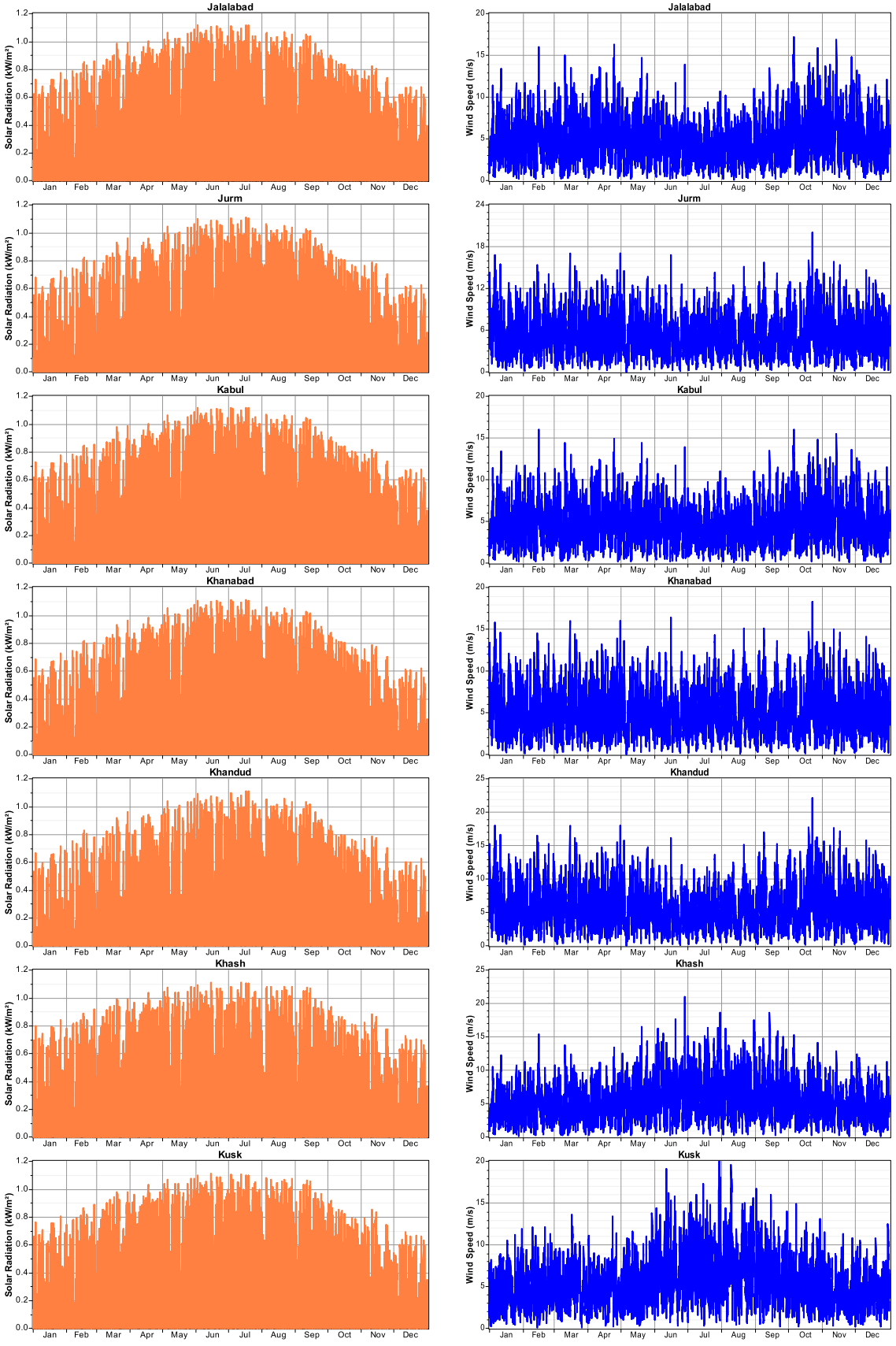

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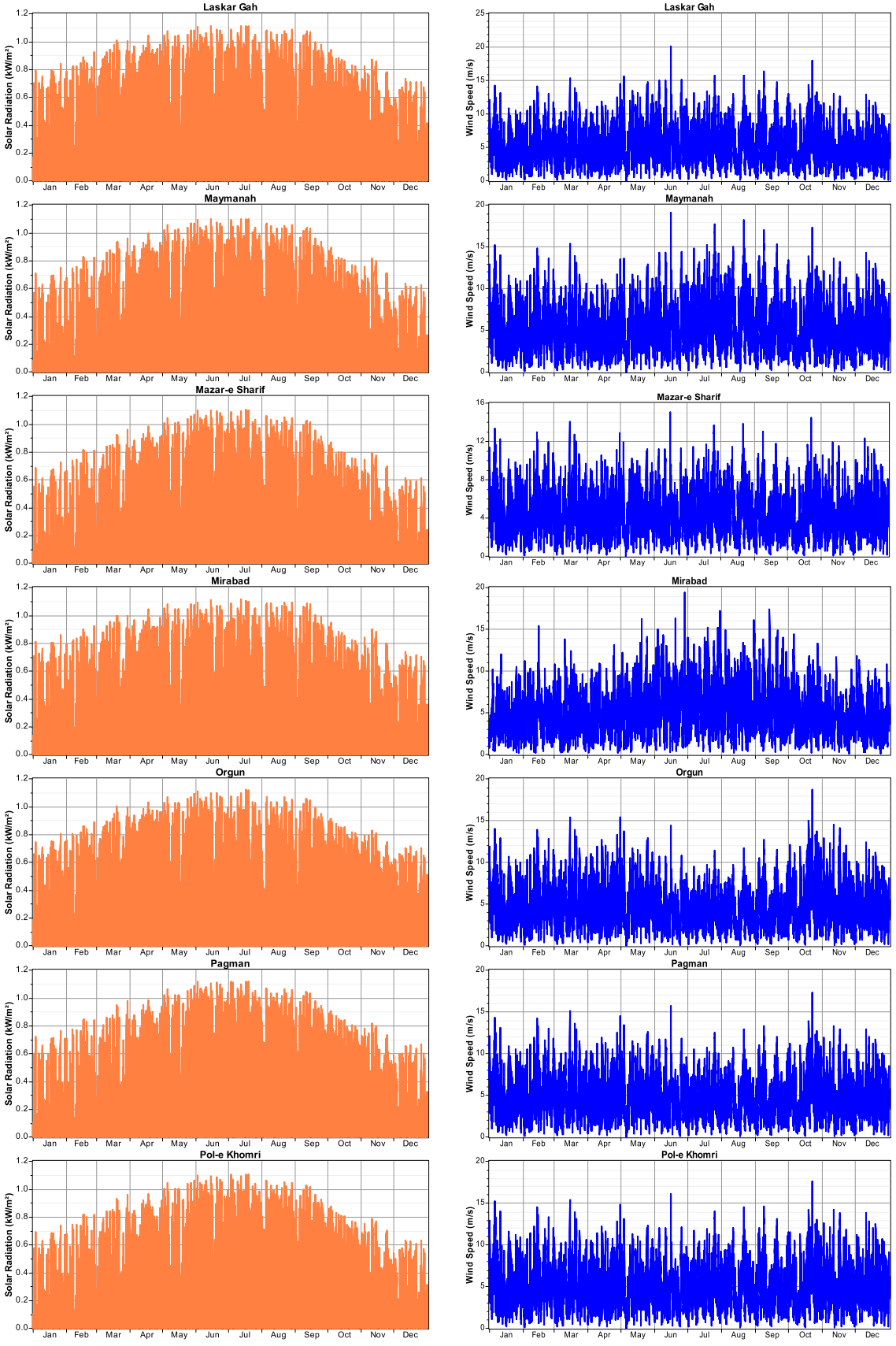

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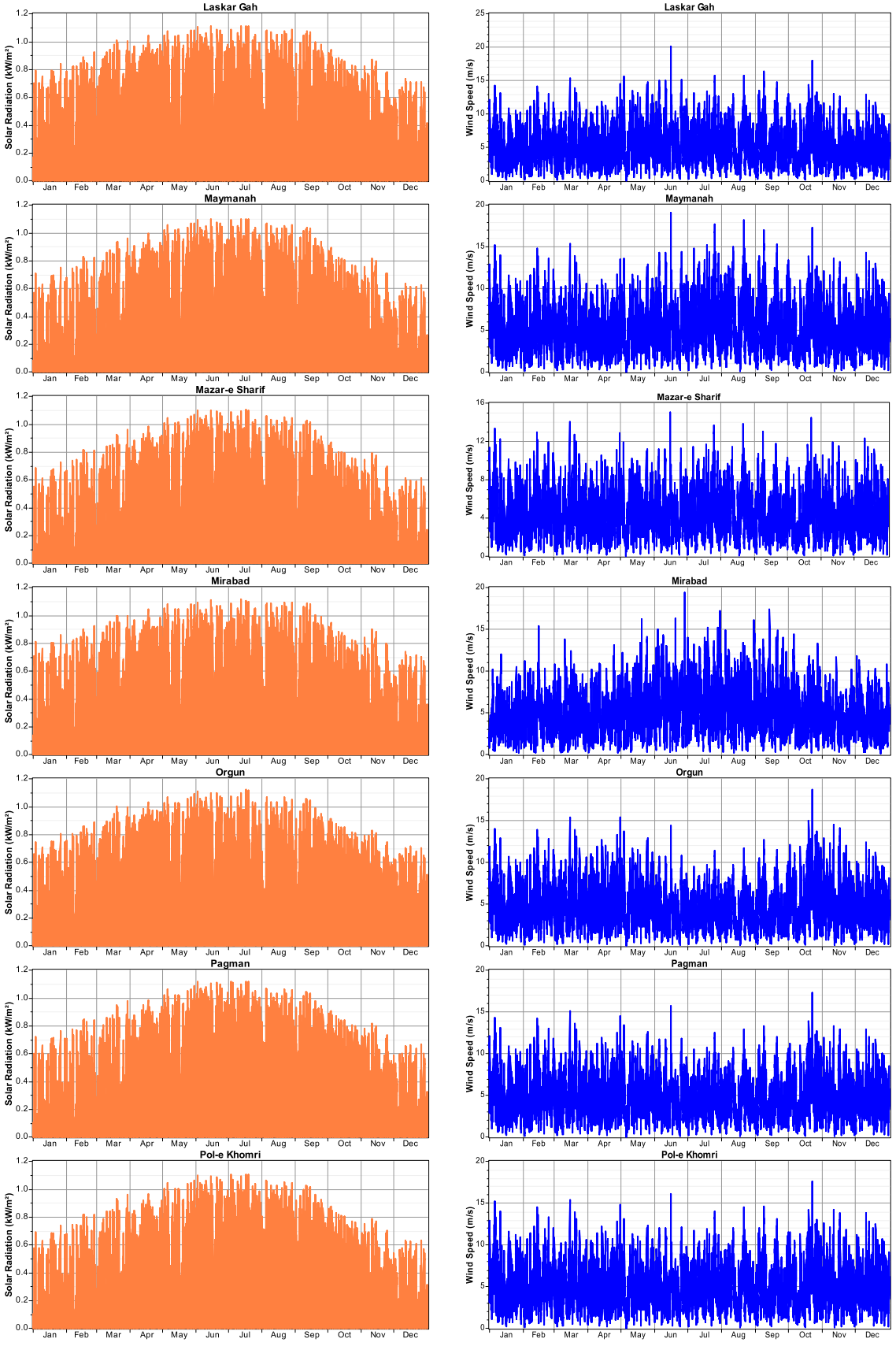

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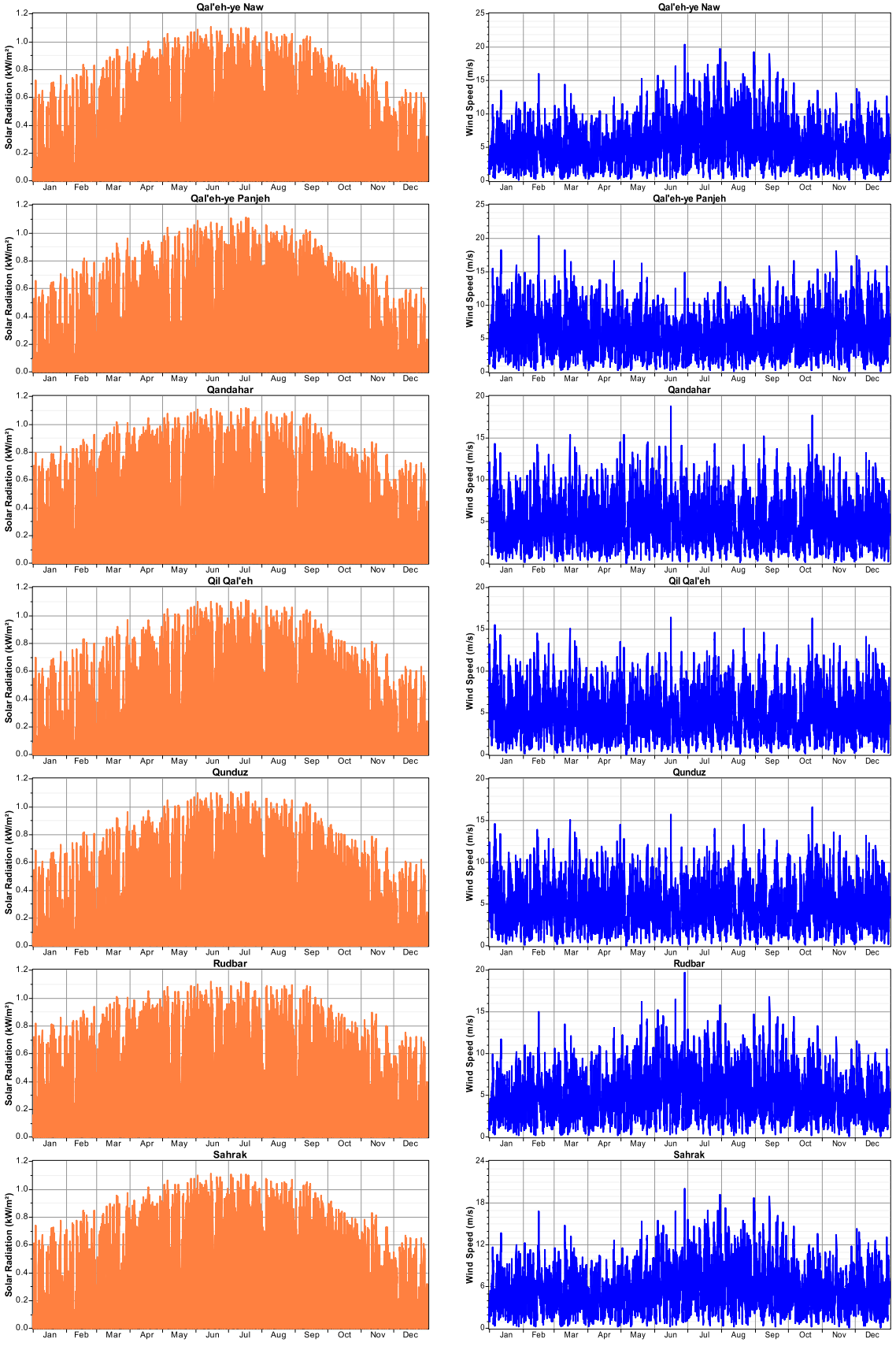

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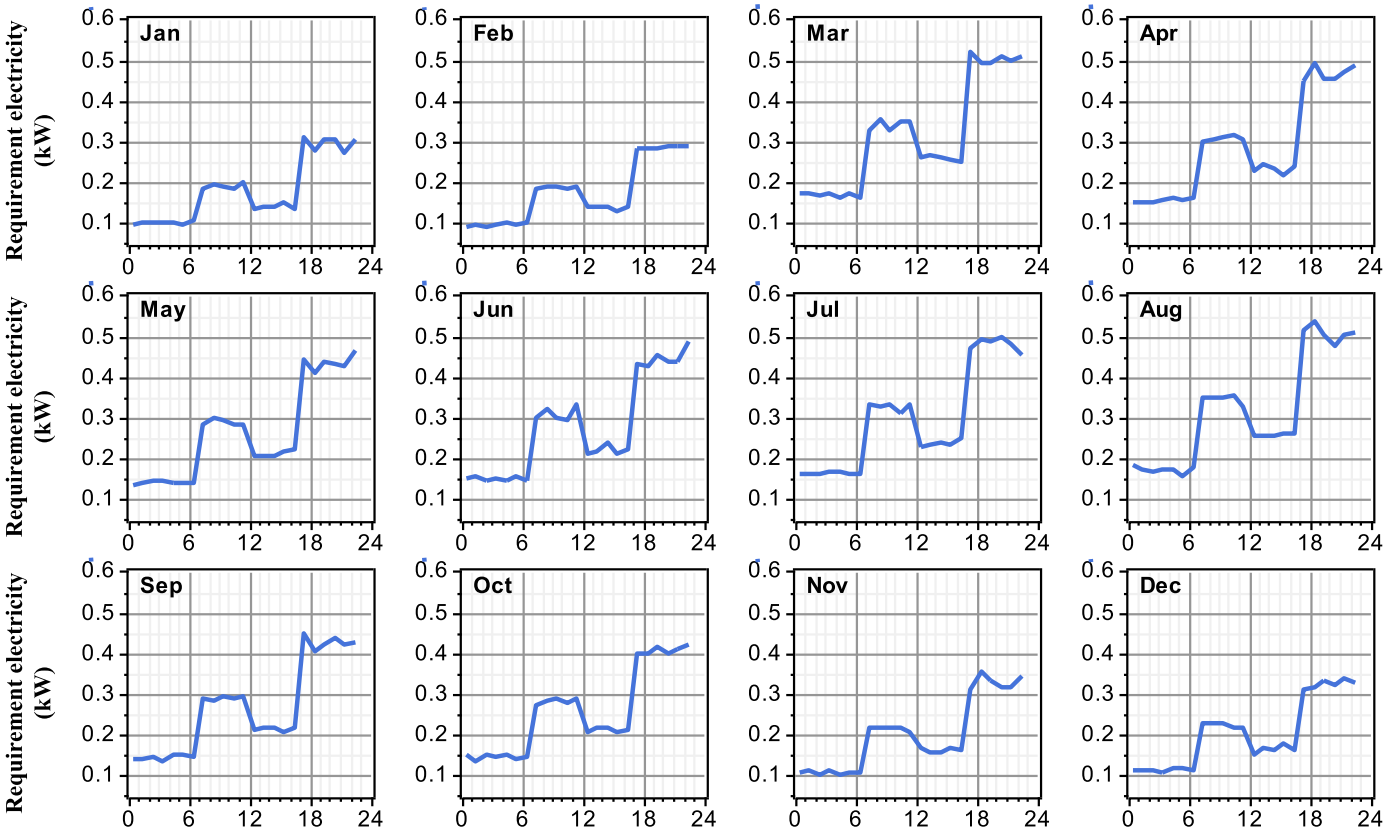


Fig. 5. Amount of electricity requirement (kWh/yr.).

studied stations is shown in Fig. 3. From Appendix A it is obvious that annual average clearness index, annual average radiation and annual average wind speed are 0.6133, 5.1452 kWh/m^2-day and 5.0043 m/s, respectively.

The wind speed and solar radiation data used in this paper are 20-year-average [31] recorded by NASA satellites. Also, one-year histograms of wind speed and sun radiation of all 46 studied stations are shown in Fig. 4. Given the one-year histogram of wind speed for studied stations, large variations in wind speed could be observed for all stations especially Deh Rawud, Farah, Fayazabad, Herat, Jurm, Khash, Laskar Gah, Qal'eh-ye Naw, Qal'eh-ye Panjeh, Sahrak, Sangin, Sindand and Taywarah. However, Balkh, Gardez and Mazar-e Sharif stations experience less variability in wind speed.

It is noteworthy that clearness index is a criterion for the degree of cloudiness in the sky which is calculated by HOMER Software based on solar radiation received at the earth's surface and latitude of studied area [32,33]. Clearness index for a clear sky is equal to the maximum value which is 0.8 and for a totally cloudy sky is equal to minimum value which is about zero [32,33].

To overcome the intermittent nature of renewable energy sources and as a backup for times when power generated from renewable energies cannot meet the demand [34], a diesel generator is also used in simulations process. The average diesel price of $ 0.81/L is considered for simulations [35] and, given the annual rise in prices, an annual growth rate of 10% during useful years of project is considered (for 25 years).

The most important input data to HOMER is electricity requirement during a typical 24 h in various months which is illustrated in Fig. 5. Fig. 5 presents the required electricity (kW) during a day for various months of a year which is based on the consumption bills of a house in Afghanistan. The average annual electricity requirement during a day is equal to 5.9 kW with day-to-day random variability of 15.1%.

Prices, sizes, useful life, and other practical information about simulation components are presented in Table 2. Price charts in Table 2 are also plotted based on the number of equipment used for simulation. For the solar cell, for example, the software was allowed to choose the optimal option between 0 and 4 solar cells. Also, this number was 20, 2, 2, and 2 for batteries, turbines, converter, and generator, respectively. Multiplying the number of equipment by their capital and replacement prices would give the price charts.

The equations used for the equipment's capacity, and also the economic values of the project, etc. are explained in the following [36].

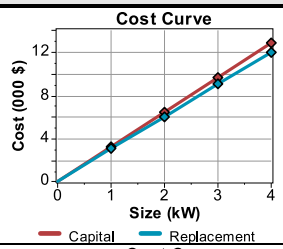
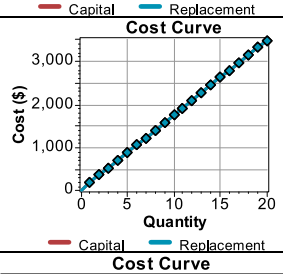
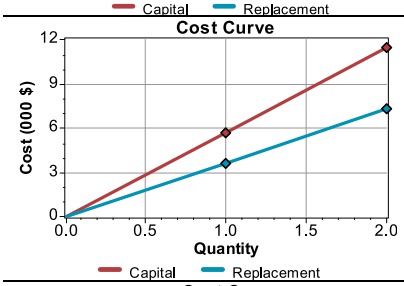
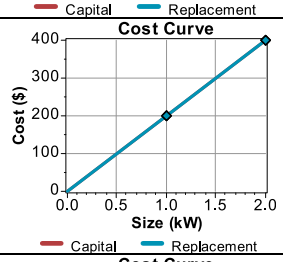
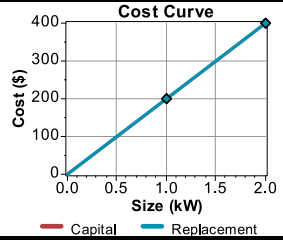
3.1. Solar cells

To calculate the output power of PV cells, HOMER uses the following relation:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\bar{G_T}}{\bar{G_{T.STC}}} \right) [1+\alpha_p (T_c - T_{c.STC})] \quad (2)$$

where Y_{pv} is the output power (kW) of solar cell under standard conditions, f_{pv} is derating factor, $\bar{G_T}$ is the incident radiation on the cell's surface on a monthly basis ($\frac{kW}{m^2}$), $G_{T,\bar{STC}}$ is the incident radiation on the

Table 2
Information of simulated hybrid power-plant [37].

Size of equipment	Lifetime	Operating & Maintenance ($)	Replacement ($)	Purchase ($)	Component
	20 year	0	3000	3200	PV
	845 kwh	5	174	174	Battery Trojan T-105
	20 year	100	3650	5725	Wind turbineBWC XL.1
	10 year	10	200	200	Converter
	15000 hour	0.5	200	200	Generator

cell's surface ($\frac{1kW}{m^2}$) under standard conditions, α_p is temperature coefficient of power ($\frac{\%}{°C}$), T_c is the cell's surface temperature (°C) at each time interval, $T_{c,\ STC}$ is the cell's surface temperature under standard conditions (i.e. 25 °C). Due to the fact that the selected cell does not include the temperature effect in the simulations, α_p has a value of zero in the current study.

3.2. Wind turbine

Using the power and wind speed curve at hub height, HOMER calculates the output power of wind turbines. Clearly, the power curve generally captures the wind turbine performance under standard temperature and pressure conditions. To calculate it for real world conditions, as it is shown in the following relation, the software multiplies the power curve output by the air density ratio.

$$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG.STP} \quad (3)$$

where ρ is the real air density ($\frac{kg}{m^3}$), ρ_0 is the air density under standard temperature and pressure conditions which is equal to 1.225, and $P_{WTG.STP}$ is the wind turbine output power under standard conditions.

3.3. Batteries

For each step, HOMER calculates the maximum amount of power that the storage bank can absorb. The maximum charge power varies from one time step to the next according to its state of charge and its recent charge and discharge history.

HOMER imposes three separate limitations on the battery's maximum charge power. The first limitation comes from the kinetic battery model which is calculated by the following relation:

$$P_{batt.cmax.kbm} = \frac{kQ_1e^{-k\Delta t}+Qkc(1-e^{-k\Delta t})}{1-e^{-k\Delta t}+c(k\Delta t - 1+e^{-k\Delta t})} \quad (4)$$

where Q_1 is the available energy (kWh) in the battery at the beginning of the time step, Q is the total amount of energy (kWh) in the battery at the beginning of the time step, c is battery capacity ratio, k is the battery rate constant ($\frac{1}{h}$), and Δt is the length of the time step (h).

The second limitation relates to the maximum charge rate of battery which is given by:

$$P_{batt.cmax.mcr} = \frac{(1-e^{-\alpha_c\Delta t})(Q_{max}-Q)}{\Delta t} \quad (5)$$

where α_c is the battery's maximum charge rate ($\frac{A}{Ah}$), Q_{max} is the total capacity of the battery (kWh). The third limitation relates to the battery's maximum charge current, which is given by the following equation:

$$P_{batt.cmax.mcc} = \frac{N_{batt}I_{max}V_{nom}}{1000} \quad (6)$$

where N_{batt} is the number of batteries, I_{max} is the battery's maximum charge current (A), and V_{nom} is the battery's nominal voltage (V). According to the following relation, HOMER sets the maximum battery charge power equal to the least these three values.

$$P_{batt.cmax} = \frac{Min(P_{batt.cmax.kbm}.\ P_{batt.cmax.mcr}.\ P_{batt.cmax.mcc})}{\eta_{batt.c}} \quad (7)$$

where $\eta_{batt,c}$ is the batteries charge efficiency.

3.4. Diesel generator

By inserting the fuel curve inputs, HOMER draws the corresponding efficiency curve. The fuel curve describes the amount of fuel the generator consumes to produce electricity. HOMER assumes that the fuel curve is a straight line. The following relation gives the generator's fuel consumption in units/h as a function of its electrical output:

$$\dot{m}_{fuell} = F_0Y_{gen} + \quad F_1P_{gen} \quad (8)$$

where F_0 is the fuel curve intercept coefficient (units/h-kW), F_1 is the fuel curve slope (units/h.kW), Y_{gen} is the rated capacity of the generator (kW), and P_{gen} is the electrical output of the generator (kW). The generator's electrical efficiency, which is defined as the electrical energy coming out divided by the chemical energy of the fuel going in, is calculate by the following relation in HOMER:

$$\eta_{gen} = \frac{3.6\ \ P_{gen}}{\dot{m}_{fuel}LHV_{fuel}} \quad (9)$$

where LHV_{fuel} is the lower heating value of the fuel (MJ/kg).

3.5. Converter

The inverter efficiency determines how much of the DC power is converted to AC power. Converter may be a synchronous inverter (with AC generator) or a switched inverter. Rectifier efficiency is defined as the ratio of DC power to the applied AC power. It should be noted that HOMER assumes constant values for inverter and rectifier efficiencies. While most solid-state converters are less efficient at lower loads due to standing losses.

Table 3
Properties of Diesel fuel.

Emission Factors	
Carbon monoxide (g/L of fuel)	6.5
Unburned hydrocarbons (g/L of fuel)	0.72
Particulate matter (g/L of fuel)	0.49
Proportion of fuel sulfur converted to PM (%)	2.2
Nitrogen oxides (g/L of fuel)	58
Destination of fuel carbon	
Carbon dioxide	99.5%
Carbon monoxide	0.4%
Unburned hydrocarbons	0.1%
Total	100%
Fuel Properties	
Lower heating value	43.2 MJ/kg
Density	820 kg/m^3
Carbon content	88%
Sulfur content	0.33%

3.6. Cost computations

Discount rate is used to convert one-time costs into equivalent annual costs. HOMER uses interest rate to give discount factor and calculate the annual costs from Net Present Cost (NPC). To calculate annual real interest rate (i) from nominal interest rate (i′), HOMER uses the following equation:

$$i = \frac{i'-f}{1+f} \quad (10)$$

where f is the annual inflation rate. HOMER assumes a constant inflation rate for all costs.

The total NPC is captured by dividing total annual cost by capital recovery factor. HOMER calculates the capital recovery factor (CRF) by:

$$CRF = \frac{i(1+i)^N}{(1+i)^N-1} \quad (11)$$

Also, the price per kWh of electricity produced is obtained by total annual costs divided by the real cost of electrical load.

3.7. Emissions

In the present study, about 2.62 kg of CO_2 emission is considered per liter of fuel consumed. This value is obtained based on the Table 3. Also, the specifications of the fuel used (diesel) is given in Table 3.

3.8. Wind turbulence intensity

Turbine power output (P) is calculated by the following relation [38]:

$$P = \frac{1}{2}\rho AV^3C_p \quad (12)$$

where ρ is the air density ($\frac{kg}{m^3}$), A is the swept area (m^2), V is the wind speed (m/s), and C_p is the wind turbine power coefficient for the corresponding wind speed [38].

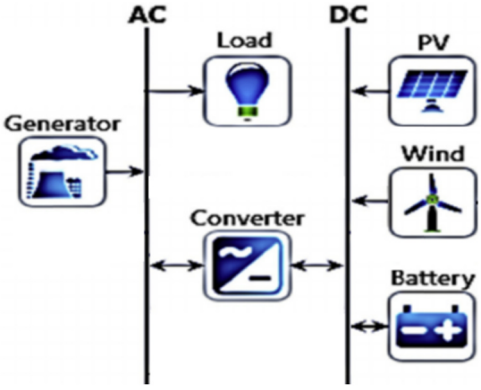


Fig. 6. Schematic of studied power-plant.

Since Afghanistan is a land-locked and mountainous country, it is of importance to analyze wind turbulence in the studied stations due to the fact that wind turbines are designed according to the wind speed and turbulence characteristics. Also, wind turbulence significantly influences the fatigue loads applied on turbine and highly turbulent winds reduce the generation output and accelerate the fatigue in the mechanical components of the wind turbine [39,40]. Turbulence intensity (TI) is calculated by the following relation [39,40]:

$$TI = \frac{\sigma}{V_{ave}} \quad (13)$$

where σ is the standard deviation and V_{ave} is the average wind speed. There are three cases of low-, medium-, and high-turbulence intensity which are used to refer to the values below 0.1, 0.1–0.25, and above 0.25, respectively [39].

4. Results

Fig. 6 shows a schematic representation of simulated power-plant. The reason behind using batteries is to store energy during times when production exceeds consumption, and returned to the grid when production falls below consumption. As a backup system for periods where the batteries are exhausted and there is no power generation from renewable energies, a diesel generator was utilized in simulations. Due to using fossil fuels, however, there will be some emission produced, mainly CO_2, which is included in the calculations.

Appendix B shows calculation results of c and k parameters used in Weibull function for all stations in Afghanistan. From results it is obvious that Kabul, Qal'eh-ye Panjeh, and Sangin stations, with a k value of 2.04, and Orgun station, with a k value of 1.95, have the widest and narrowest wind speed distributions, respectively.

Also, the windiest stations are Fayazabad, Qal'eh-ye Panjeh, and Sindand with a c value of 6.33. The worst station, with regard to blow of wind, is Mazar-e Sharif with a c value of 4.89.

Results of the studied solar-wind system for all 46 stations in Afghanistan are presented in Appendix C. These results indicate that, due to lower costs and higher potential, using solar cells is more cost-effective than wind turbines at all stations.

The lowest cost of generating energy is reported for Deh Rawud and Uruzgan stations, with a price of 0.612$/kWh and the highest cost of generating energy is recorded at Balkh station with a price of 0.711$/kWh. At all the studied stations, two 1 kW solar panels, one 1 kW generator, and one converter are used whose main difference is due to generator operating hours and the number of batteries.

The least net present cost is related to Uruzgan station, with a price of $12006, which consists of 2 solar cells, 1 diesel generator, 10 batteries, and 1 converter. The highest net present price is associated with Balkh station, with a price of $13941, which is composed of 2 solar cells, 1 diesel generator, 11 batteries, and 1 converter. The highest and lowest rate of using diesel generator, with 311 and 25 operating hours, is related to Balkh and Qandahar stations, respectively. In other words, providing 87% and 99% of their required energy from renewable energies, Balkh and Qandahar are environmentally the worst and best stations, respectively.

Annual emission production, which is directly proportional to diesel consumption, is 253 kg CO_2/ 96 L diesel consumed for Balkh stations and 19.6 kg CO_2 / 7 L diesel consumed for Qandahar station. However, there are also other pollutants like Co, SO_2, NO, etc., but since CO_2 is the primary part of emissions (more than 97%), only CO_2 has been studied in the present paper. It is noteworthy, however, no penalty is imposed on producing excess emissions since no punitive policy for these issues is in place in Afghanistan.

According to the results in Appendix C, average price per kWh of energy generated in Afghanistan is $ 0.638, the average percentage of using renewables is about 96.46%, and the average rate of CO_2 emitted is 70.39 kW/yr.

Appendix C illustrates that, for each 46 available stations in Afghanistan, renewables alone cannot meet the energy demand and using diesel generator is a must.

Appendix D represents the details of power generated during a year for Uruzgan, Balkh, Qandahar, Lashkar Gah, and Fayazabad stations. These stations are selected because they are characterized by the lowest net present cost, highest net present cost (highest rate of emissions), the least rate of emissions, highest solar radiation and highest wind speed, respectively.

From the results of Appendix D for Balkh station it could be seen that, during 9 month of the year, energy demand could be met by solar radiation alone. The electricity generated from solar cells and diesel generator is 3784 kWh/yr and 285 kWh/yr, respectively. From total 4069 kWh electricity generated annually, 34.6% of which is excess energy which could be sold to the grid to reduce costs of power generation and return on investment. Solar cells and diesel generator operate about half of the year and 3.55% of days a year, respectively. Also, annual losses (in kWh) for battery, converter, and rectifier are 223, 234, and 34, respectively.

According to the results of Appendix D for Fayazabad station it could be observed that during 9 months of year, solar energy alone can meet electricity requirement. From total 3885 kWh of electricity generated annually, 3808 kWh of which is provided by solar cells and the rest is supplied by diesel generator. An excess energy of 32.1% is produced. Solar cells and diesel generator have been in operation during 49.8% and 0.9% of the year, respectively. Losses in batteries, converter, and rectifier are 222, 238, and 9 kWh/yr. which is 12% of total energy produced.

At Lashkar Gah station, solar energy is sufficient during 8 month of the year to meet power demand and during the remaining 4 months, a diesel generator has to be used. Despite high radiation in this station, solar cells cannot provide 100% of the required energy due to reasons like climatic conditions of the area (cloudiness, sunny hours, etc.). This suggests the necessity of using HOMER in simulations. It should be noted that GIS graphs should not be the only basis to judge definitely of the energy generation capability of an area. From 3964 kWh of electricity generated annually, 3919 kWh of which is produced by solar cells and the remaining by diesel generator. About 33.5% of excess

Table 4
Turbulence Intensity for studied stations.

Station	TI	Station	TI
Anar darreh	0.205	Khash	0.168
Bagran	0.126	Kusk	0.207
Bala Morgab	0.119	Laskar Gah	0.086
Balkh	0.053	Maymanah	0.105
Bamiyan	0.061	Mazar-e Sharif	0.040
Cagcaran	0.125	Mirabad	0.149
Carikar	0.060	Orgun	0.104
Ciras	0.087	Pagman	0.047
Dawlatabad	0.078	Pol-e Khomri	0.033
Deh Rawud	0.080	Qal'eh-ye Naw	0.173
Deh su	0.100	Qal'eh-ye Panjeh	0.112
Farah	0.197	Qandahar	0.061
Fayazabad	0.056	Qil Qal'eh	0.047
Gardez	0.127	Qunduz	0.024
Gaz Ab	0.082	Rudbar	0.137
Gazni	0.062	Sahrak	0.154
Gurian	0.188	Sang-e Carak	0.065
Heart	0.194	Sangin	0.114
Jalalabad	0.149	Shibarghan	0.067
Jurm	0.055	Sindand	0.212
Kabul	0.113	Taywarah	0.157
Khanabad	0.036	Uruzgan	0.052
Khandud	0.097	Zargun Sahr	0.077

electricity is also produced. Operating hours of solar cells and diesel generator are 50% and 0.7% of year, respectively. Losses related to converter, rectifier and battery are altogether about 11.78% of total production.

Results of Appendix D for Qandahar station show that during 10 months of the year there is no need to use fossil duels and only in 2 months, totally about 25 h, a diesel generator has to be used. From a total 3962 kWh of electricity generated annually, about 33.5% of which is excess production which could be sold to the grid to reduce costs per kWh of energy generated. Altogether, about 11.86% of energy generated is lost due to losses in battery, converter, and rectifier.

According to the results of Appendix D related to Uruzgan station it could be seen that for 3 months of the year there is a need to use diesel generator and in the remaining days of the year solar cells suffice to meet electricity demand. It is notable that the highest annual energy production by solar cells (4047 kWh) is related to Uruzgan station which is provided by operating solar cells for 4385 h during a year. Furthermore, 42 kWh of energy is generated by diesel generator within 57 working hours for 3 months. Annual losses of battery, converter, and rectifier are 228, 239, and 4 kWh, respectively.

According to the results obtained in the present work, since 2 rooftop-mounted PV cells are required to provide the electricity demand (of a household), the limitations of ground-mounted cells do not exist. Furthermore, because in the most critical scenario that occurs in Balkh station, only 253 kg of CO_2 is produced annually, there also exists no more environmental limitation. Since Afghanistan is a vast country and there is no extensive main grid network and given the high costs of main grid development [41], it seems that the main limitation for the development of hybrid solar-wind plants in this country is connection to the main grid.

There are no specific environmental regulations for the use of wind turbines in Afghanistan. Afghanistan ministry of energy and water offers the long term land lease for wind farm investors, 25% subsidy, tax incentives, security assistance, long term power purchase agreement, right to buy and attractive tariff. Development of renewable energy sector in Afghanistan needs regulatory environmental issues to develop legal basis for private sector, transparent guidelines, technical standards, and oversight/monitoring (especially O&M) [42,43]. Clearly, the amount and pattern of subsidy will vary depending on the technology, location, and the design of the renewable project.

The analysis results of turbulence intensity parameter are presented in Table 4. According to the results, it is obvious that 23 stations in Afghanistan have a low turbulence intensity (below 0.1) which means the mechanical components of wind turbines are under low fatigue loads and the rest stations have a medium turbulence intensity (between 0.1 and 0.25) which means the mechanical components of wind turbines are under medium fatigue loads. The highest and lowest values of turbulence intensity parameter are associated with Sindand (0.212) and Qunduz (0.024) stations respectively. Also, the average turbulence intensity of 0.105 is obtained for all 46 stations.

5. Conclusion

In recent years, given the fact that Afghanistan is a less developed country, little effort has been devoted to estimate potential of renewable energies in this country. Previous works were either restricted to a particular area [44–46] or not so accurately estimated this potential [47]. In the present study, an off-grid hybrid solar-wind system has been studied for 46 stations using HOMER and GIS Software. Simulation results indicate that in order to find locations prone to using renewable energies, a combined use of these two software is needed. Also, some parameters are studied including consumed diesel fuel, CO_2 emissions produced, cost per kWh of energy generated, percentage of energy provided by renewables, and net present price for all 46 available stations. The results can be expressed as follows:

- According to results, the highest annual solar radiation, with a value of 5.63 kWh/m^2-day, was related to Lashkar Gah stations and the highest average wind speed, with a value of 5.9 m/s, was reported for Fayazabad station.
- Results showed that Kabul, Qal'eh-ye Panjeh, and Sangin stations had the widest and Orgun station had the narrowest wind speed distribution. Also, the windiest locations were Fayazabad, Qal'eh-ye Panjeh, and Sindand stations. But, Mazar-e Sharif as the worst station regarding of the wind speed.
- Results suggested that the lowest generation cost per kWh of energy was $0.612 related to Deh Rawud, and Uruzgan stations, and the highest generation cost per kWh of energy was $ 0.711 for Balkh stations.
- According to the results, with using diesel generator only for 2 months of the year and utilizing solar cells for the remaining 10 months, Qandahar station had the highest percentage of using renewables which was also consistent with the other results.

Acknowledgement

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Appendix A

Station	Longtitude	Latitude	Elevation (m)	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Anar darreh	61.7	32.8	751	Wind (m/s)	4.3	4.6	4.7	4.4	5.3	6.5	7.2	6.89	6.3	5.2	4.3	4.4	5.3
				Solar (kwh/m^2·day)	3.32	4.18	5.02	6.01	6.78	7.33	6.98	6.69	5.84	4.66	3.52	2.91	5.27
				Clearness index	0.597	0.611	0.588	0.594	0.610	0.639	0.620	0.640	0.645	0.636	0.603	0.564	0.615
Bagran	65.1	33.1	2349	Wind (m/s)	4.7	4.9	4.8	4.3	5.1	6.1	6.2	5.9	5.8	5.1	4.4	4.9	5.2
				Solar (kwh/m^2·day)	2.91	3.74	4.66	5.95	7.13	7.53	7.27	6.78	6.04	5.05	3.72	2.78	5.3
				Clearness index	0.537	0.557	0.552	0.591	0.642	0.655	0.645	0.651	0.673	0.701	0.653	0.555	0.624
Bala Morgab	63.3	35.6	973	Wind (m/s)	4.6	4.7	4.6	4.2	4.6	5.5	6	5.9	5.5	4.9	4.5	4.7	5
				Solar (kwh/m^2·day)	2.38	3.21	4.09	5.45	6.82	7.27	7.15	6.63	5.66	4.28	2.91	2.18	4.84
				Clearness index	0.469	0.502	0.498	0.548	0.615	0.630	0.633	0.641	0.644	0.619	0.543	0.468	0.583
Balkh	66.9	63.8	685	Wind (m/s)	4.5	4.5	4.4	4.1	4.1	4.6	4.9	4.8	4.5	4.3	4.4	4.5	4.5
				Solar (kwh/m^2·day)	2.39	3.22	4.06	5.56	6.81	7.71	7.1	6.57	5.43	4.23	2.93	2.14	4.85
				Clearness index	4.343	1.796	0.971	0.764	0.680	0.678	0.665	0.793	1.042	1.713	3.650	7.962	0.720
Bamiyan	67.5	34.8	3220	Wind (m/s)	4.6	4.8	4.6	4	4.4	4.8	4.7	4.5	4.5	4.3	4.0	4.7	4.5
				Solar (kwh/m^2·day)	2.76	3.48	4.19	5.47	6.99	7.78	7.41	6.8	6.12	4.99	3.51	2.53	5.18
				Clearness index	0.528	0.532	0.504	0.547	0.629	0.675	0.657	0.655	0.690	0.707	0.637	0.525	0.617
Cagcaran	65.3	34.5	2795	Wind (m/s)	4.8	5	4.8	4.3	4.9	5.9	6.3	6.1	5.8	5	4.5	5.1	5.2
				Solar (kwh/m^2·day)	2.86	3.58	4.47	5.8	6.92	7.48	7.43	6.84	6.11	4.96	3.54	2.62	5.23
				Clearness index	0.546	0.547	0.537	0.579	0.623	0.649	0.658	0.659	0.688	0.703	0.641	0.542	0.622
Carikar	69.2	35.0	3041	Wind (m/s)	4.9	4.8	4.9	5	4.6	4.7	4.5	4.5	4.8	5.5	5.2	4.8	4.8
				Solar (kwh/m^2·day)	2.59	3.2	4.06	5.15	6.42	7.56	7.66	7.05	5.97	4.6	3.2	2.4	5
				Clearness index	0.509	0.499	0.494	0.517	0.578	0.655	0.678	0.681	0.679	0.664	0.596	0.513	0.601
Ciras	66.0	35.4	2452	Wind (m/s)	5.1	5.1	4.9	4.4	4.7	5.5	5.9	5.8	5.5	5	4.9	5.2	5.1
				Solar (kwh/m^2·day)	2.56	3.32	4.2	5.57	6.74	7.41	7.33	6.67	5.73	4.57	3.12	2.38	4.97
				Clearness index	0.504	0.519	0.511	0.560	0.607	0.642	0.649	0.645	0.652	0.660	0.582	0.510	0.598
Dawlatabad	64.9	36.4	584	Wind (m/s)	4.6	4.6	4.4	3.9	4.2	4.8	5.2	5.1	4.8	4.5	4.5	4.6	4.6
				Solar (kwh/m^2·day)	2.26	3.17	4.05	5.52	6.65	7.26	7.07	6.51	5.57	4.13	2.77	2.07	4.76
				Clearness index	0.461	0.507	0.500	0.558	0.600	0.628	0.626	0.632	0.641	0.609	0.533	0.461	0.579
Deh Rawud	65.5	32.6	1613	Wind (m/s)	4.8	5	4.9	4.5	5.3	5.9	5.5	5.2	5.5	5.2	4.6	4.9	5.1
				Solar (kwh/m^2·day)	3.4	4.34	5.25	6.42	7.24	7.38	7.1	6.62	5.73	4.9	3.76	3.11	5.44
				Clearness index	0.610	0.634	0.615	0.634	0.652	0.643	0.630	0.633	0.633	0.668	0.643	0.602	0.635
Deh su	63.3	30.4	748	Wind (m/s)	4.2	4.5	4.6	4.5	5.3	5.7	5.2	4.8	5.1	5	4.2	4.3	4.8
				Solar (kwh/m^2·day)	3.62	4.53	5.27	6.26	6.94	7.19	6.85	6.62	6.1	5.09	3.58	3.17	5.46

Farah	62.1	32.4	867	Clearness index	0.613	0.634	0.602	0.613	0.625	0.630	0.610	0.630	0.661	0.670	0.580	0.575	0.622
				Wind (m/s)	4.4	4.7	4.8	4.6	5.4	6.8	7.3	6.9	6.5	5.5	4.5	4.6	5.5
				Solar (kwh/m^2·day)	3.34	4.25	5.09	6.22	6.98	7.54	7.19	6.74	5.7	4.62	3.47	2.93	5.34
Fayazabad	70.6	37.1	2387	Clearness index	0.599	0.620	0.596	0.615	0.628	0.657	0.638	0.645	0.629	0.630	0.593	0.566	0.623
				Wind (m/s)	6	5.7	5.7	5.7	5.3	5	5.3	5.4	5.4	5.9	6.1	5.8	5.9
				Solar (kwh/m^2·day)	2.41	3.13	4.14	5.58	6.87	8.07	8	7.26	6.17	4.53	3.03	2.22	5.13
Gardez	69.2	33.6	2326	Clearness index	0.508	0.513	0.518	0.568	0.620	0.698	0.708	0.707	0.718	0.681	0.601	0.513	0.630
				Wind (m/s)	4.5	4.7	4.8	5.1	4.7	4.2	3.7	3.7	4.2	5.6	5.3	4.4	4.6
				Solar (kwh/m^2·day)	3.07	3.82	4.83	6.09	7.34	7.8	7.12	6.29	5.6	4.89	3.82	2.98	5.31
Gaz Ab	66.3	33.4	2548	Clearness index	0.568	0.570	0.573	0.605	0.661	0.678	0.631	0.604	0.624	0.680	0.672	0.596	0.626
				Wind (m/s)	4.6	4.9	4.7	4.2	4.8	5.4	5.3	5.1	5.1	4.7	4.1	4.7	4.8
				Solar (kwh/m^2·day)	3.08	3.9	4.8	6.11	7.39	7.87	7.38	6.88	6.19	5.16	3.83	2.9	5.46
Gazni	68.4	33.6	2442	Clearness index	0.569	0.582	0.569	0.607	0.665	0.684	0.655	0.660	0.690	0.717	0.673	0.579	0.644
				Wind (m/s)	4.5	4.8	4.7	4.6	4.6	4.5	4.1	4	4.3	5	4.6	4.5	4.5
				Solar (kwh/m^2·day)	3.01	3.77	4.65	5.91	7.31	7.75	6.9	6.37	5.71	4.94	3.79	2.87	5.25
Gurian	61.5	34.3	976	Clearness index	0.557	0.563	0.551	0.587	0.658	0.674	0.612	0.611	0.637	0.687	0.667	0.574	0.619
				Wind (m/s)	4.4	4.5	4.6	4.2	4.9	6.1	6.9	6.7	6	4.9	4.3	4.5	5.2
				Solar	2.87	3.7	4.67	5.81	6.8	7.48	7.25	6.72	5.74	4.42	3.15	2.54	5.1
Heart	62.2	34.4	1453	Clearness index	0.547	0.564	0.561	0.580	0.612	0.649	0.642	0.647	0.646	0.626	0.570	0.525	0.607
				Wind (m/s)	4.5	4.7	4.7	4.3	5	6.4	7.2	7	6.3	5.2	4.5	4.7	5.4
				Solar (kwh/m^2·day) (kwh/m^2·day)	2.77	3.62	4.57	5.73	6.78	7.31	7.09	6.62	5.8	4.48	3.19	2.53	5.05
Jalalabad	70.4	34.4	1409	Clearness index	0.528	0.552	0.549	0.572	0.610	0.635	0.628	0.637	0.653	0.634	0.577	0.523	0.601
				Wind (m/s)	4.7	4.8	5	5.6	4.8	4.3	3.8	3.9	4.4	6.1	5.8	4.7	4.8
				Solar (kwh/m^2·day)	3.02	3.67	4.67	5.76	7.04	7.89	7.49	6.53	5.72	4.82	3.61	2.82	5.26
Jurm	70.8	36.9	3157	Clearness index	0.576	0.560	0.561	0.575	0.634	0.685	0.664	0.629	0.644	0.682	0.653	0.583	0.626
				Wind (m/s)	5.4	5.2	5.3	5.4	5.0	4.9	4.9	4.9	5.2	5.8	5.6	5.2	5.2
				Solar (kwh/m^2·day)	2.51	3.16	4.08	5.09	6.26	7.38	7.42	7.03	6.05	4.46	3.09	2.32	4.91
Kabul	69.2	34.5	2132	Clearness index	0.513	0.507	0.504	0.515	0.565	0.639	0.657	0.682	0.697	0.659	0.596	0.518	0.598
				Wind (m/s)	4.7	4.8	4.8	5.1	4.7	4.3	3.9	3.9	4.4	5.7	5.3	4.5	4.7
				Solar (kwh/m^2·day)	2.92	3.61	4.55	5.71	7.06	8.03	7.78	6.76	5.85	4.96	3.66	2.78	5.31
Khanabad	69.1	36.7	1650	Clearness index	0.557	0.551	0.547	0.570	0.636	0.697	0.689	0.651	0.659	0.703	0.663	0.575	0.633
				Wind (m/s)	5.1	4.9	5	5.1	4.7	4.8	4.9	4.9	5	5.3	5.3	5	5
				Solar (kwh/m^2·day)	2.46	3.21	4.16	5.56	6.73	7.95	7.75	6.85	5.81	4.52	3.07	2.23	5.03
Khandud	72.3	36.9	4134	Clearness index	0.502	0.514	0.514	0.562	0.607	0.688	0.686	0.665	0.669	0.667	0.592	0.497	0.613
				Wind (m/s)	5.8	5.6	5.6	5.7	5.4	4.7	4.7	4.9	5.6	6.4	6.2	5.6	5.5
				Solar (kwh/m^2·day)	2.39	3.07	3.93	4.92	5.94	7.03	7.24	6.73	5.81	4.16	2.94	2.18	4.7

				Clearness index	0.488	0.492	0.486	0.498	0.536	0.608	0.641	0.653	0.669	0.614	0.567	0.487	0.573
Khash	62.8	31.5	574	Wind (m/s)	4.3	4.6	4.6	4.6	5.4	6.5	6.6	6.2	6.1	5.4	4.4	4.4	5.3
				Solar (kwh/m^2·day)	3.36	4.26	4.81	5.94	6.67	7.05	6.74	6.39	5.66	4.56	3.44	2.93	5.15
				Clearness index	0.585	0.609	0.556	0.584	0.600	0.616	0.599	0.610	0.619	0.611	0.573	0.549	0.595
Kusk	62.0	33.3	1038	Wind (m/s)	4.4	4.6	4.7	4.4	5.2	6.5	7.3	7.1	6.3	5.1	4.3	4.5	5.4
				Solar (kwh/m^2·day)	3.12	4	4.93	5.96	6.89	7.52	7.3	6.8	5.83	4.64	3.39	2.73	5.26
				Clearness index	0.576	0.597	0.584	0.592	0.620	0.654	0.647	0.653	0.560	0.644	0.596	0.545	0.620
Laskar Gah	64.4	31.6	896	Wind (m/s)	4.6	4.8	4.8	4.6	5.4	5.9	5.4	5.1	5.4	5.2	4.6	4.6	5
				Solar (kwh/m^2·day)	3.5	4.43	5.27	6.08	6.86	7.28	6.89	6.52	5.76	4.94	3.71	3.08	5.63
				Clearness index	0.610	0.634	0.609	0.598	0.617	0.636	0.612	0.622	0.630	0.662	0.618	0.577	0.620
Maymanah	64.8	35.9	1772	Wind (m/s)	4.9	5.0	4.8	4.3	4.7	5.6	6.1	5.9	5.6	5	4.8	5.1	5.1
				Solar (kwh/m^2·day)	2.49	3.31	4.17	5.55	6.77	7.27	7.21	6.53	5.7	4.4	3.05	2.32	4.91
				Clearness index	0.492	0.518	0.508	0.558	0.610	0.630	0.639	0.631	0.649	0.637	0.570	0.499	0.591
Mazar-e Sharif	67.1	36.7	1089	Wind (m/s)	4.3	4.4	4.4	4.1	4.1	4.4	4.7	4.5	4.3	4.2	4.2	4.4	4.3
				Solar (kwh/m^2·day)	2.42	3.22	4.09	5.52	6.69	7.65	7.08	6.56	5.39	4.18	2.97	2.18	4.84
				Clearness index	0.494	0.516	0.505	0.558	0.603	0.662	0.627	0.637	0.621	0.617	0.572	0.486	0.589
Mirabad	61.8	30.4	483	Wind (m/s)	4.2	4.6	4.6	4.5	5.3	6	6.1	5.7	5.7	5.1	4	4.2	5
				Solar (kwh/m^2·day)	3.38	4.21	4.82	5.86	6.62	7	6.73	6.48	5.77	4.72	3.6	2.98	5.18
				Clearness index	0.572	0.590	0.551	0.574	0.596	0.613	0.599	0.617	0.625	0.621	0.584	0.541	0.593
Orgun	69.2	33.0	1845	Wind (m/s)	4.5	4.7	4.8	4.9	4.7	4.2	3.9	3.8	4.2	5.4	5.1	4.4	4.6
				Solar (kwh/m^2·day)	3.35	4.21	5.11	6.31	7.02	7.38	6.55	6.14	5.69	5	3.99	3.26	5.34
				Clearness index	0.618	0.627	0.605	0.627	0.632	0.642	0.581	0.589	0.634	0.694	0.700	0.650	0.628
Pagman	69.0	34.6	2966	Wind (m/s)	4.6	4.8	4.7	4.6	4.6	4.6	4.3	4.2	4.4	5	4.7	4.6	4.6
				Solar	2.72	3.47	4.19	5.42	7.01	7.96	7.77	6.87	5.99	4.98	3.59	2.6	5.22
				Clearness index	0.519	0.530	0.503	0.541	0.631	0.691	0.689	0.662	0.675	0.706	0.650	0.538	0.622
Pol-e Khomri	68.7	36.0	2469	Wind (m/s)	4.9	4.9	4.8	4.7	4.5	4.7	4.8	4.7	4.8	5.1	5	4.9	4.8
				Solar (kwh/m^2·day) (kwh/m^2·day)	2.62	3.35	4.16	5.18	6.37	7.53	7.53	6.91	5.91	4.6	3.24	2.44	4.99
				Clearness index	0.533	0.535	0.513	0.523	0.574	0.652	0.667	0.670	0.680	0.677	0.622	0.542	0.607
Qal'eh-ye Naw	63.1	35.0	2005	Wind (m/s)	4.7	4.8	4.8	4.3	5	6.3	7	6.8	6.2	5.2	4.5	4.9	5.4
				Solar (kwh/m^2·day)	2.63	3.42	4.38	5.66	6.94	7.43	7.26	6.79	5.97	4.67	3.25	2.51	5.08
				Clearness index	0.517	0.533	0.533	0.568	0.625	0.644	0.643	0.656	0.679	0.674	0.605	0.537	0.611
Qal'eh-ye Panjeh	72.8	37.0	4379	Wind (m/s)	6.4	6.1	6.1	5.7	5.3	4.6	4.8	4.9	5.2	5.9	6.2	6.2	5.6
				Solar (kwh/m^2·day)	2.38	3.14	4.08	4.97	5.9	6.95	7.38	7.01	6.14	4.26	2.89	2.12	4.78
				Clearness index	0.501	0.514	0.511	0.506	0.533	0.601	0.653	0.683	0.714	0.641	0.573	0.489	0.587
Qandahar	65.7	31.6	1143	Wind (m/s)	4.6	4.8	4.8	4.6	5.3	5.5	4.9	4.6	5	5.1	4.6	4.7	4.9
				Solar (kwh/m^2·day)	3.5	4.42	5.3	6.21	6.92	7.29	6.85	6.47	5.67	4.95	3.71	3.17	5.38

				Clearness index	0.610	0.632	0.613	0.611	0.623	0.637	0.609	0.617	0.620	0.663	0.618	0.594	0.621
Qil Qal'eh	67.1	35.3	2708	Wind (m/s)	5	4.9	4.7	4.3	4.4	4.8	5	4.9	4.8	4.7	4.7	5	4.8
				Solar (kwh/m^2·day)	2.39	3.1	3.79	4.96	6.29	7.4	7.23	6.64	5.76	4.49	3.08	2.24	4.79
				Clearness index	0.471	0.484	0.461	0.498	0.567	0.641	0.640	0.642	0.655	0.648	0.574	0.480	0.576
Qunduz	68.9	36.7	775	Wind (m/s)	4.7	4.7	4.7	4.6	4.4	4.6	4.8	4.7	4.6	4.8	4.8	4.7	4.7
				Solar (kwh/m^2·day)	2.41	3.17	4.02	5.36	6.54	7.76	7.66	6.73	5.56	4.37	3	2.17	4.9
				Clearness index	0.492	0.508	0.497	0.542	0.590	0.672	0.678	0.653	0.640	0.645	0.578	0.484	0.597
Rudbar	62.6	30.2	604	Wind (m/s)	4.1	4.5	4.5	4.5	5.3	6.1	5.6	5.2	5.5	5.1	4.1	4.1	4.9
				Solar (kwh/m^2·day)	3.5	4.45	5.02	6.08	6.75	7.1	6.75	6.44	5.82	4.81	3.64	3.1	5.29
				Clearness index	0.592	0.623	0.573	0.595	0.608	0.622	0.601	0.613	0.631	0.633	0.590	0.562	0.605
Sahrak	64.3	34.1	2579	Wind (m/s)	4.8	5	4.9	4.3	5	6.2	6.8	6.6	6.2	5.2	4.6	5.1	5.4
				Solar (kwh/m^2·day)	2.75	3.53	4.43	5.75	7.01	7.59	7.51	6.93	6.11	4.86	3.4	2.59	5.21
				Clearness index	0.524	0.538	0.532	0.574	0.631	0.659	0.666	0.667	0.688	0.687	0.614	0.535	0.620
Sang-e Carak	66.4	35.9	2669	Wind (m/s)	5	5	4.8	4.3	4.6	5.2	5.5	5.3	5.2	4.9	4.8	5.1	5
				Solar (kwh/m^2·day)	2.38	3.12	3.8	5.05	6.45	7.46	7.33	6.76	5.86	4.56	3.08	2.21	4.85
				Clearness index	0.470	0.488	0.463	0.508	0.581	0.646	0.649	0.654	0.668	0.660	0.576	0.475	0.584
Sangin	64.8	32.1	1510	Wind (m/s)	4.7	4.9	4.9	4.6	5.4	6.3	6.1	5.8	5.9	5.4	4.7	4.8	5.3
				Solar (kwh/m^2·day)	3.28	4.22	5.12	6.21	7.15	7.44	7.08	6.62	5.87	4.97	3.69	3.03	5.4
				Clearness index	0.587	0.615	0.599	0.613	0.643	0.648	0.629	0.633	0.648	0.677	0.630	0.585	0.629
Shibarghan	65.7	36.7	574	Wind (m/s)	4.6	4.6	4.4	4	4.2	4.7	5.1	5	4.8	4.5	4.5	4.7	4.6
				Solar (kwh/m^2·day)	2.31	3.15	4.03	5.53	6.72	7.36	7.12	6.52	5.48	4.17	2.76	2.09	4.78
				Clearness index	0.472	0.505	0.498	0.559	0.606	0.637	0.630	0.633	0.631	0.615	0.532	0.466	0.581
Sindand	62.2	33.3	1601	Wind (m/s)	4.6	4.8	4.8	4.5	5.3	6.8	7.6	7.4	6.7	5.4	4.5	4.7	5.6
				Solar (kwh/m^2·day)	3.14	4.08	5.02	6.08	6.97	7.51	7.22	6.79	5.97	4.79	3.51	2.82	5.33
				Clearness index	0.580	0.609	0.595	0.604	0.627	0.653	0.640	0.652	0.665	0.665	0.617	0.563	0.628
Taywarah	64.4	33.5	2557	Wind (m/s)	4.8	4.9	4.9	4.4	5.2	6.5	6.8	6.5	6.3	5.3	4.6	5	5.4
				Solar (kwh/m^2·day)	2.95	3.78	4.67	5.98	7.11	7.58	7.29	6.77	6.01	4.94	3.61	2.84	5.3
				Clearness index	0.546	0.564	0.554	0.594	0.640	0.659	0.647	0.650	0.670	0.686	0.635	0.568	0.624
Uruzgan	66.6	32.9	2123	Wind (m/s)	4.7	5	4.8	4.5	5.1	5.3	4.8	4.6	5	5	4.5	4.7	4.8
				Solar (kwh/m^2·day)	3.36	4.26	5.22	6.43	7.32	7.45	7.01	6.54	5.9	5.09	3.91	3.14	5.47
				Clearness index	0.604	0.623	0.611	0.636	0.659	0.649	0.622	0.626	0.652	0.695	0.670	0.608	0.639
Zargun Sahr	68.5	32.9	2206	Wind (m/s)	4.5	4.8	4.8	4.7	4.8	4.5	4	3.9	4.3	5.1	4.7	4.5	4.5
				Solar (kwh/m^2·day)	3.16	4.03	5.27	6.61	6.98	7.85	6.95	6.51	5.73	4.99	3.98	3.23	5.45
				Clearness index	0.568	0.589	0.617	0.653	0.628	0.684	0.617	0.623	0.633	0.681	0.682	0.626	0.636

Appendix B

Station	k	c	Station	k	c
Anar darreh	1.99	6.04	Khash	1.97	5.94
Bagran	2.03	5.86	Kusk	2.00	6.07
Bala Morgab	2.03	5.62	Laskar Gah	1.97	5.67
Balkh	1.99	5.04	Maymanah	1.96	5.81
Bamiyan	1.99	5.07	Mazar-e Sharif	1.99	4.89
Cagcaran	2.03	5.88	Mirabad	2.00	5.64
Carikar	1.99	5.47	Orgun	1.95	5.13
Ciras	1.97	5.83	Pagman	1.99	5.18
Dawlatabad	1.97	5.19	Pol-e Khomri	2.00	5.44
Deh Rawud	1.97	5.76	Qal'eh-ye Naw	1.96	6.07
Deh su	1.96	5.39	Qal'eh-ye Panjeh	2.04	6.33
Farah	2.00	6.22	Qandahar	1.98	5.51
Fayazabad	1.99	6.33	Qil Qal'eh	1.99	5.38
Gardez	2.02	5.16	Qunduz	2.00	5.28
Gaz Ab	1.97	5.41	Rudbar	2.01	5.51
Gazni	1.98	5.09	Sahrak	1.99	6.10
Gurian	2.00	5.84	Sang-e Carak	1.98	5.62
Heart	2.00	6.08	Sangin	2.04	5.97
Jalalabad	2.00	5.44	Shibarghan	1.98	5.18
Jurm	1.99	5.90	Sindand	2.00	6.33
Kabul	2.04	5.27	Taywarah	1.99	6.14
Khanabad	2.00	5.64	Uruzgan	1.99	5.45
Khandud	1.96	6.23	Zargun Sahr	1.97	5.13

Appendix C

Station						Total Net Present Cost ($)	Cost of Energy ($/kWh)	Renewable Fraction	Co_2 (kg/yr)	Diesel (L)	Generator (hrs)
Anar darreh	2	-	1	11	1	12231	0.624	0.98	49.7	19	70
Bagran	2	-	1	12	1	12280	0.626	0.98	40	15	52
Bala Morgab	2	-	1	14	1	12964	0.661	0.96	81.2	31	107
Balkh	2	-	1	11	1	13941	0.711	0.87	253	96	311
Bamiyan	2	-	1	11	1	12545	0.640	0.95	90.4	34	113
Cagcaran	2	-	1	11	1	12399	0.632	0.96	70.9	27	94
Carikar	2	-	1	12	1	12815	0.653	0.95	98	37	127
Ciras	2	-	1	12	1	12707	0.648	0.96	86	33	113
Dawlatabad	2	-	1	14	1	12996	0.663	0.96	86.2	33	110
Deh Rawud	2	-	1	11	1	12012	0.612	0.99	27.8	11	37
Deh su	2	-	1	10	1	12210	0.623	0.97	64.3	24	90
Farah	2	-	1	11	1	12220	0.623	0.98	49.5	19	69
Fayazabad	2	-	1	13	1	12690	0.647	0.96	68.4	26	83
Gardez	2	-	1	11	1	12195	0.622	0.98	44.6	17	60
Gaz Ab	2	-	1	12	1	12114	0.618	0.99	21.6	8	27
Gazni	2	-	1	11	1	12267	0.625	0.97	52.9	20	71
Gurian	2	-	1	12	1	12464	0.635	0.97	64	24	77
Heart	2	-	1	11	1	12570	0.641	0.96	88.9	34	119
Jalalabad	2	-	1	11	1	12277	0.626	0.97	53.8	20	71
Jurm	2	-	1	13	1	12778	0.651	0.96	77.5	29	97
Kabul	2	-	1	11	1	12210	0.623	0.98	47.5	18	62
Khanabad	2	-	1	12	1	12715	0.648	0.96	85.6	32	112
Khandud	2	-	1	12	1	13109	0.668	0.93	130	50	164
Khash	2	-	1	12	1	12444	0.634	0.97	58.6	22	76
Kusk	2	-	1	12	1	12261	0.625	0.98	36.8	14	50
Laskar Gah	2	-	1	11	1	12150	0.619	0.98	41.8	16	58
Maymanah	2	-	1	12	1	12786	0.652	0.95	96.1	37	125
Mazar-e Sharif	2	-	1	12	1	12866	0.656	0.95	101	38	135
Mirabad	2	-	1	12	1	12434	0.634	0.97	56.9	22	76
Orgun	2	-	1	11	1	12112	0.618	0.98	38.5	15	48
Pagman	2	-	1	11	1	12545	0.640	0.95	89.2	34	111

Station						Total Net Present Cost ($)	Cost of Energy ($/kWh)	Renewable Fraction	Co_2 (kg/yr)	Diesel (L)	Generator (hrs)
Pol-e Khomri	2	-	1	13	1	12593	0.642	0.97	58.6	22	71
Qal'eh-ye Naw	2	-	1	12	1	12467	0.636	0.97	60.6	23	79
Qal'eh-ye Panjeh	2	-	1	13	1	12976	0.662	0.95	98.2	37	122
Qandahar	2	-	1	12	1	12102	0.617	0.99	19.6	7	25
Qil Qal'eh	2	-	1	14	1	13112	0.669	0.95	98.6	37	128
Qunduz	2	-	1	12	1	12839	0.655	0.95	102	39	130
Rudbar	2	-	1	11	1	12249	0.625	0.97	55.2	21	72
Sahrak	2	-	1	11	1	12402	0.632	0.96	71.3	27	94
Sang-e Carak	2	-	1	13	1	13043	0.665	0.94	112	43	139
Sangin	2	-	1	10	1	12141	0.619	0.97	52.7	20	80
Shibarghan	2	-	1	14	1	12999	0.663	0.96	86.6	33	110
Sindand	2	-	1	11	1	12151	0.620	0.98	43.5	17	58
Taywarah	2	-	1	11	1	12235	0.624	0.98	50.4	19	71
Uruzgan	2	-	1	10	1	12006	0.612	0.98	39.8	15	57
Zargun Sahr	2	-	1	10	1	12019	0.613	0.98	38.3	15	57

Appendix D

Station	Components	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Balkh	PV Panel	0.13268	0.41036	0.58787	0.60097	0.52862	0.52409	0.51370	0.60830
	Generator	0.0975	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fayazabad	PV Panel	0.30656	0.33361	0.37853	0.43379	0.47415	0.51971	0.53165	0.53753
	Generator	0.0000	0.0000	0.0538	0.0156	0.0000	0.0000	0.0000	0.0000
Laskar Gah	PV Panel	0.40122	0.45045	0.46105	0.46115	0.47011	0.47442	0.46113	0.47106
	Generator	0.0000	0.0000	0.0278	0.0137	0.0000	0.0000	0.0000	0.0105
Qandahar	PV Panel	0.40191	0.44981	0.46527	0.47240	0.47486	0.47592	0.45972	0.46839
	Generator	0.0000	0.0000	0.0164	0.0000	0.0000	0.0000	0.0000	0.0128
Uruzgan	PV Panel	0.39271	0.43846	0.46266	0.49175	0.50058	0.48436	0.46925	0.47418
	Generator	0.0000	0.0000	0.0292	0.0103	0.0000	0.0000	0.0000	0.0175

Station	Sep.	Oct.	Nov.	Dec.	Production (kWh/yr)	Excess electricity (kWh/yr)	Hours of operation (hr/yr)	Battery Losses (kWh/yr)	Inverter/Rectifier Losses (kWh/yr)
Balkh	0.57293	0.46133	0.18274	0.06305	3784	1409	4378	223	234/34
	0.0000	0.0000	0.0944	0.1945	285		311		
Fayazabad	0.54476	0.48313	0.37494	0.29256	3808	1247	4363	222	238/9
	0.0000	0.0000	0.0000	0.0350	77		83		
Laskar Gah	0.47561	0.47716	0.40461	0.36180	3919	1329	4380	225	238/4
	0.0000	0.0000	0.0000	0.0088	45		58		
Qandahar	0.46859	0.47916	0.40538	0.37631	3940	1326	4383	229	239/2
	0.0000	0.0000	0.0000	0.0000	22		25		
Uruzgan	0.49244	0.50519	0.44671	0.38523	4047	1453	4385	228	239/4
	0.0000	0.0000	0.0000	0.0000	42		57		

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